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REAL TIME SIMULTANEOUS IN-LINE WEAR AND LUBRICANT CONDITION MONITORING

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Lubrication Branch
Fuels and Lubrication Division

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An in-line Complete Oil Breakdown Rate Analyzer (COBRA) and Quantitative Debris Monitor (QDM[R]) were installed in the oil system of an aircraft turbine engine lubricant simulator. The in-line COBRA readings correlated well with those of a standard laboratory model COBRA and total acid number of the deteriorating lubricant. Increases in QDM[R] particle counts corresponded with increases in trace iron content, which reflected abnormal wear occurring in the simulator. Analytical and direct reading ferrographic data confirmed the rapid increase and eventual modest decrease in wear debris concentration. After test completion, it was determined that a mainshaft bearing had experienced abnormal wear. Thus, for the first time successful capability for real-time simultaneous in-line wear and lubricant condition monitoring was demonstrated. Keywords: aircraft engines

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PREFACE

This technical report was prepared by the Lubrication Branch, Fuels and Lubrication Division, Aero Propulsion Laboratory (APL), Air Force Wright Aeronautical Laboratories (AFWAL), Air Force Systems Command (AFSC), Wright-Patterson Air Force Base, Ohio. The work herein was accomplished under Project 3048, Task 304806, Work Unit 30480626, "Turbine Engine Lubricant Research," during the period of June 1986 to December 1986 with Mr P. W. Centers as Project Engineer. Special acknowledgement is given to Mr L. J. DeBrohun, AFWAL/POSL and Mr M. A. Arstingstall, AFWAL/POSX, for their outstanding contribution to this effort.

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SECTION I
INTRODUCTION

Several diagnostic methods are in use today for monitoring the condition of military aircraft gas turbine engines and lubricants. Generally, oil samples are analyzed in the laboratory using several methods. The information from laboratory analysis is invaluable in determining whether an engine is experiencing abnormal wear or whether the lubricant is degraded to a point beyond which severe corrosion and coking can occur. However, oil sampling and laboratory analysis is manpower intensive, and frequently, the time required for data generation and evaluation is unacceptable. Equipment readiness would be more quickly established and maintenance costs reduced if in-line monitors were developed to eliminate some or all of the required laboratory analyses.

One instrument that has been used with success in monitoring turbine engine lubricant condition is the Complete Oil Breakdown Rate Analyzer (COBRA, NAECO Assoc, Inc., Arlington, VA) [1]. It has been documented that COBRA readings trend closely with a basic indicator of lubricant condition, total acid number (TAN) [2]. An in-line COBRA has been developed, and results of an initial evaluation are reported here.

A commercial in-line instrument used today in limited applications for diagnosing turbine engine wear is the Quantitative Debris Monitor (QDM^R, TEDECO, Glenolden, PA), a "smart" chip detector which detects ferrous debris particles (>250μm) in the oilstream. Large and total counts of particles are summed continuously for digital presentation and evaluation. In the laboratory, trace metal content of an oil is determined by methods of the Spectrometric Oil Analysis Program (SOAP) using either emission or atomic absorption spectrometric techniques. Much smaller debris particles can be detected by these methods, but large particles are not efficiently analyzed. As such, QDM^R particle counts may not correlate well with trace iron content [3] in some wear situations. With that knowledge, a QDM^R sensor was evaluated concurrently with the in-line COBRA to demonstrate simultaneous in-line engine and lubricant health monitoring capabilities.

SECTION II

EXPERIMENTAL

A test stand aircraft turbine engine bearing and lubricant simulator [4] was used to stress a polyol ester based turbine engine lubricant to predict the performance of that lubricant in turbine engine applications. The simulator consists of the number 4 and 5 bearing compartment of a J57 gas turbine engine driven and heated electrically so that realistic turbine engine conditions are simulated. It is computer controlled for unattended operation and automatically samples the lubricant at 5-hour intervals. The oil samples were sent to a laboratory for determination of viscosity at 40°C, TAN, trace metal content for 14 different metals, and COBRA analysis. Analytical ferrograms and direct reading ferrographic ratings for several samples were obtained. None of the laboratory information was available until after the simulator test was completed.

An in-line COBRA unit and a QDM® unit were installed on the simulator prior to the test. The in-line COBRA unit was mounted in a bypass line at the exit of the shell and tube lubricant cooling heat exchanger. The metal tubing delivering the lubricant to the COBRA detector resulted in lubricant temperatures being reduced by air cooling. The QDM® was located initially at the scavenge pump outlet. The QDM® was moved downstream after about 115 test hours because abnormally high particle counts were being recorded. We believed that the high counts might be the result of air bubbles and churning at the pump outlet. In-line COBRA and QDM® values were recorded at 5-hour intervals.

SECTION III

RESULTS AND DISCUSSION

TAN and laboratory COBRA readings increased rather consistently with test time as shown in Figure 1. We expected this since previous tests [2] showed that these indicators of oil condition are related. Readings from the in-line COBRA unit also increased during the test as shown in Figure 2, though the increase in the in-line unit's readings was not as steady as the rise in laboratory COBRA readings. The apparent stability of readings at 120 to 150 test hours, followed by a large jump at 155 test hours, reflects the inability of this particular instrument to register values above 80 on the 0-100 scale. After some delay in noting the instrument's limited capability, the scale was changed to the 0-200 scale. Nevertheless, there appears to be a linear correlation between the in-line COBRA readings and the laboratory COBRA readings as shown in Figure 3. There was no apparent temperature effect; because of the placement of the in-line COBRA, readings were taken at 100 $\pm$5°F, which is well within the instrument's capability, while laboratory COBRA readings were taken at room temperature. Additionally, Figure 4 shows that the in-line COBRA readings increased proportionately to TAN, similar to laboratory COBRA readings which increased as TAN increases [2].

QDM^R particle counts increased dramatically early in the test, as did the trace metal content of iron, copper, silicon, and silver in the lubricant as determined by SOAP analysis. Trace iron content and QDM^R counts are plotted versus time in Figure 5; trace copper, silicon, and silver contents are plotted versus time in Figure 6. The trace iron content of the oil increased dramatically for the first 155 hours of the test. The trace silver content peaked 15 hours into the test, followed by large increases in trace silicon and copper content.

The dramatic increase in QDM^R counts and trace content of iron, copper, silicon, and silver were related to abnormally high wear of the number 5 bearing inner race and separator. The bearing is shown in Figure 7. The separator is made of silicon bronze coated with silver; the rest of the bearing is made of SAE 52100 steel. As shown in Figure 8, the silver plating wore off the separator, allowing the exposed bronze to wear against the steel inner race, shown in Figure 9. The wear of the inner race was asymmetric; the depth of the wear tracks varied from less

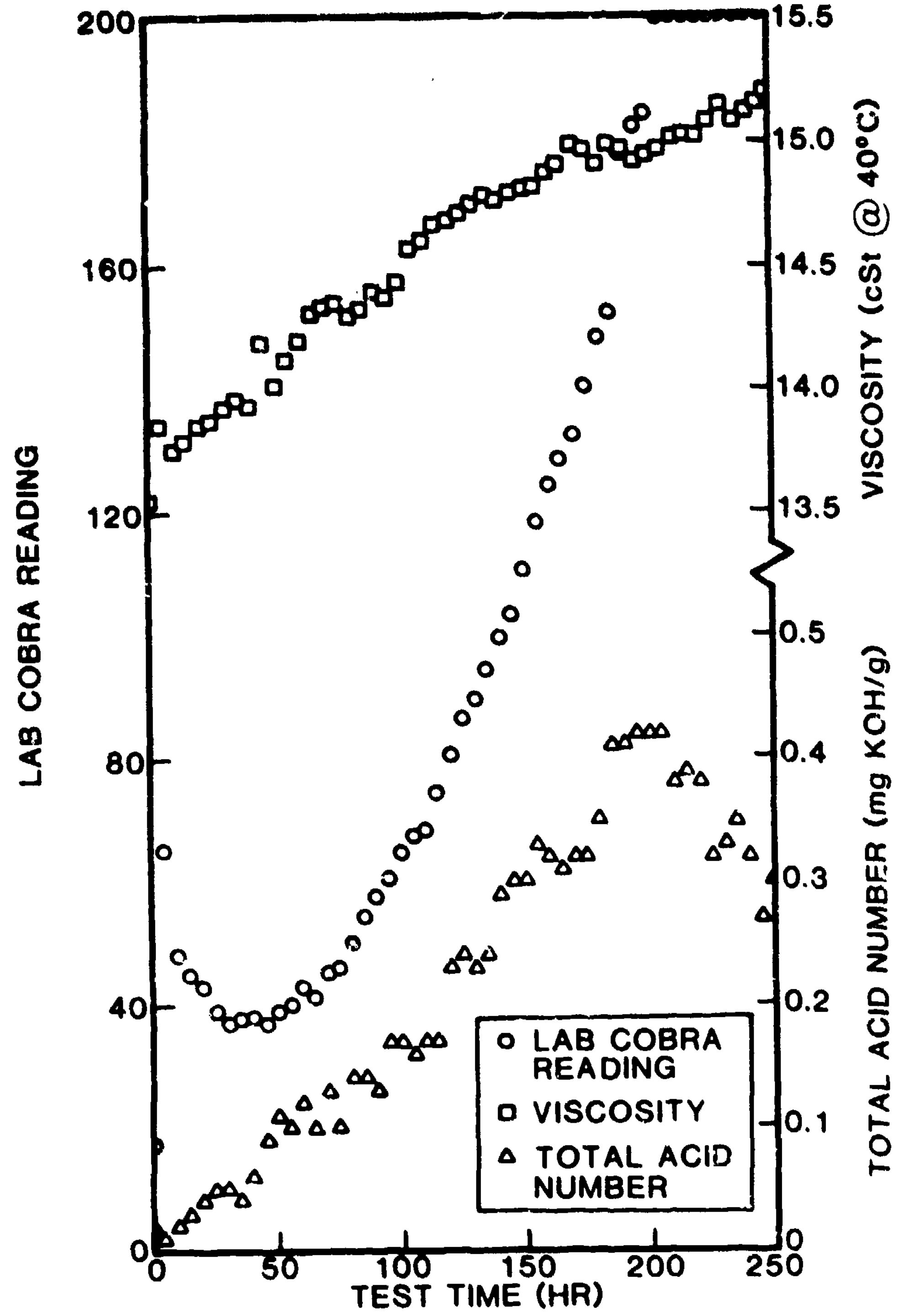


Figure 1. Lab COBRA Readings, Viscosity, and TAN of Lubricant During Test

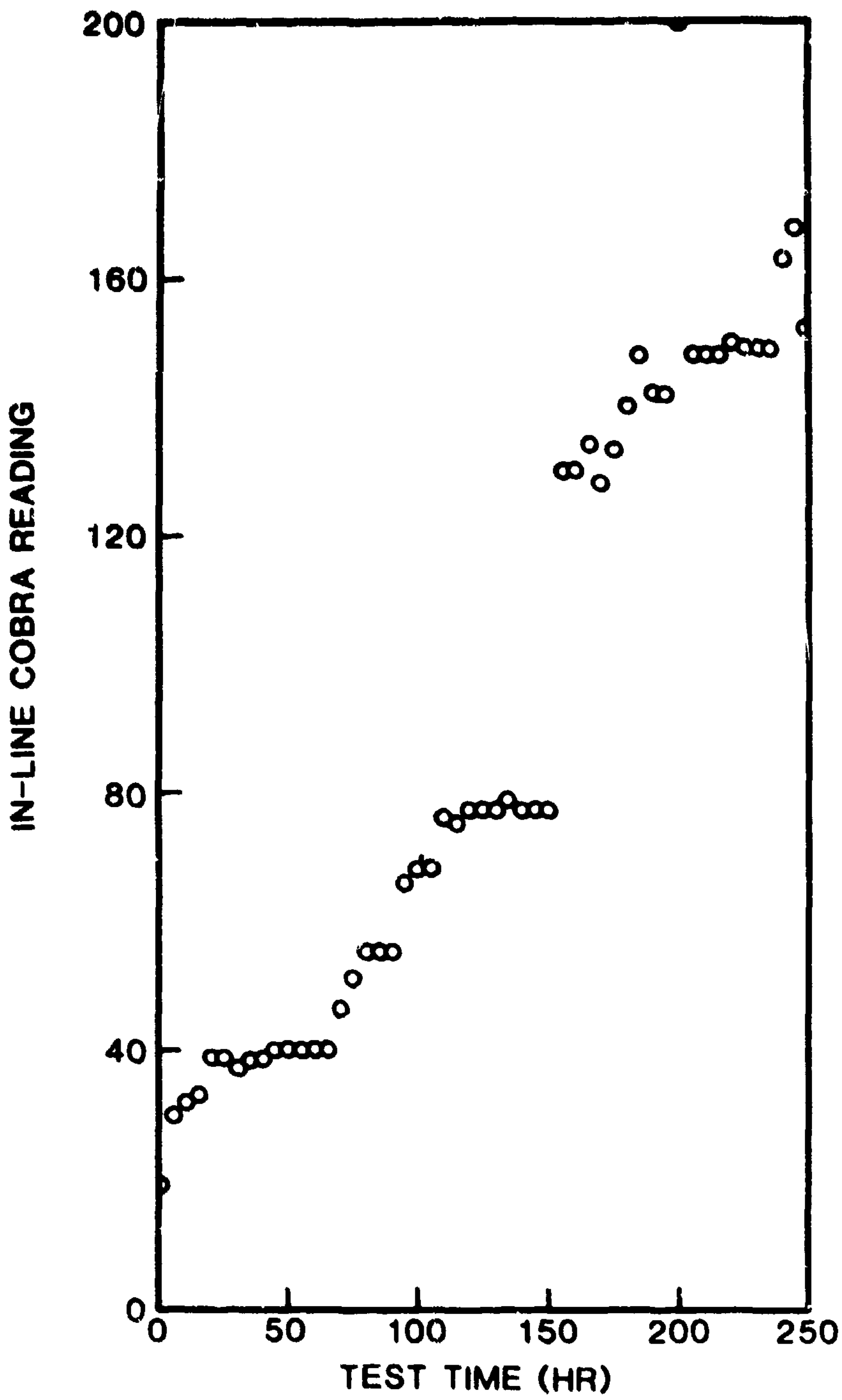


Figure 2. In-Line COBRA Readings During Test

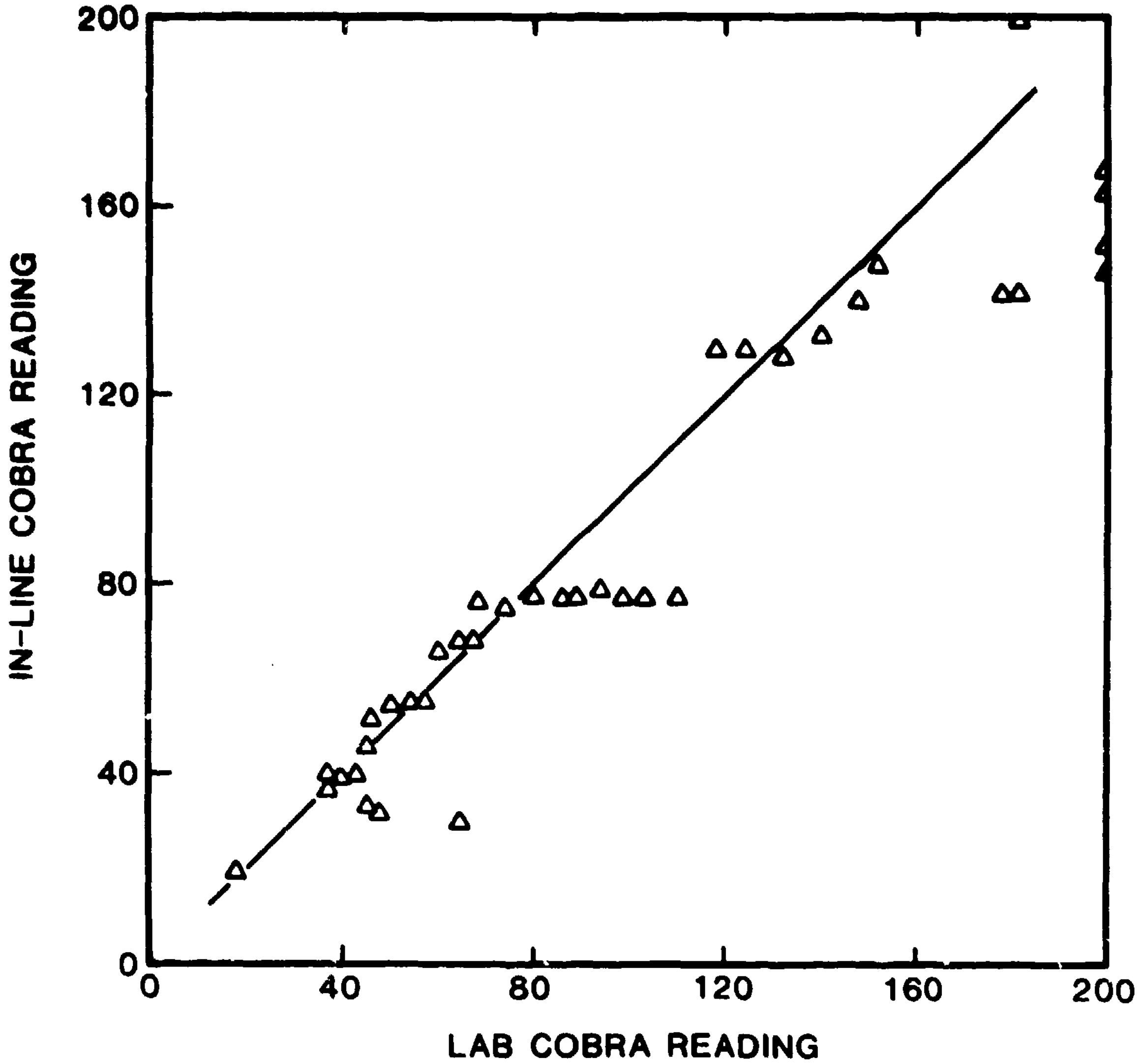


Figure 3. Correlation of In-Line COBRA and Lab COBRA Readings

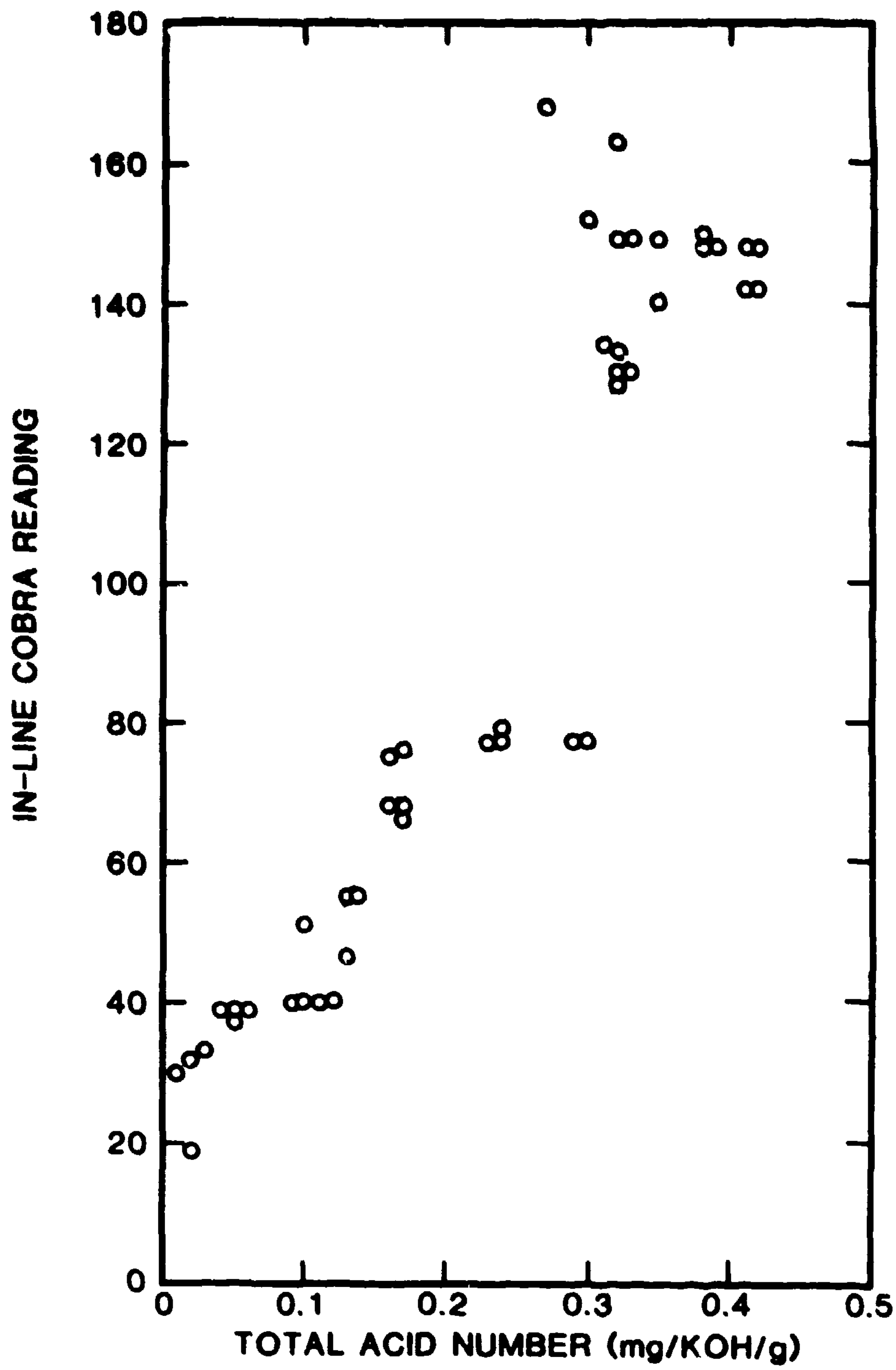


Figure 4. In-Line COBRA Versus TAN

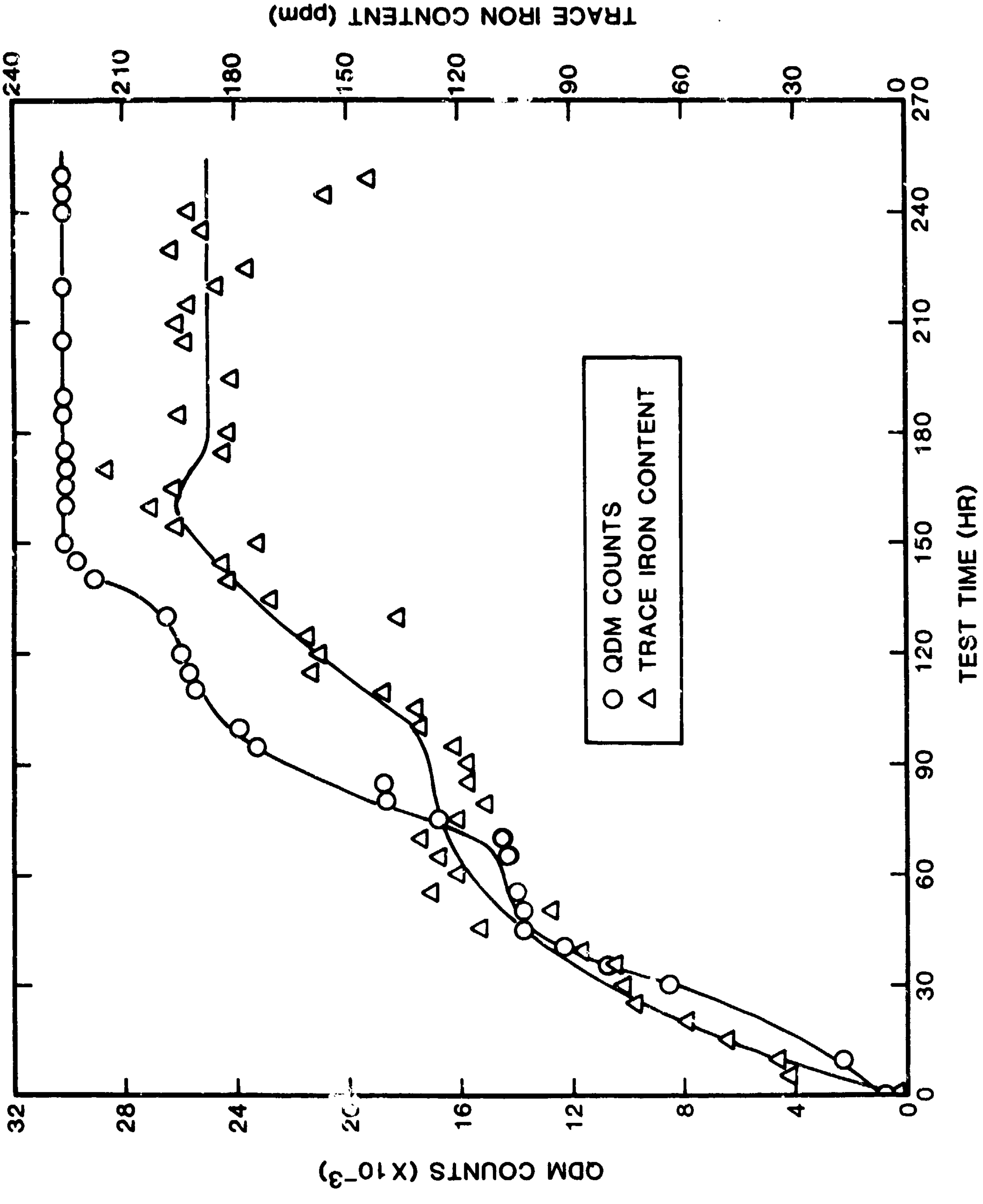


Figure 5. QDM^R Counts and Trace Iron Concentration During Test

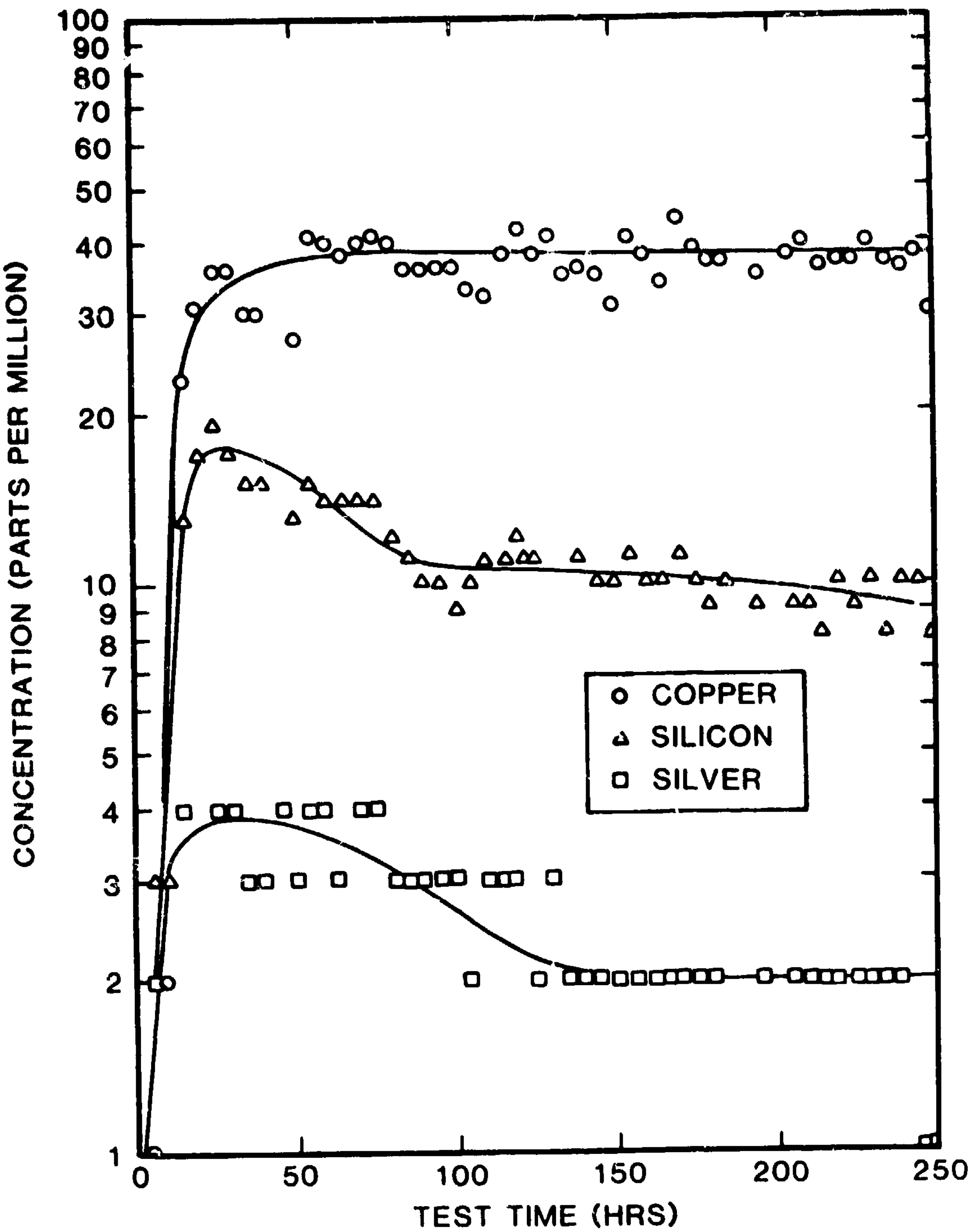


Figure 6. Trace Wear Metal Concentration During Test

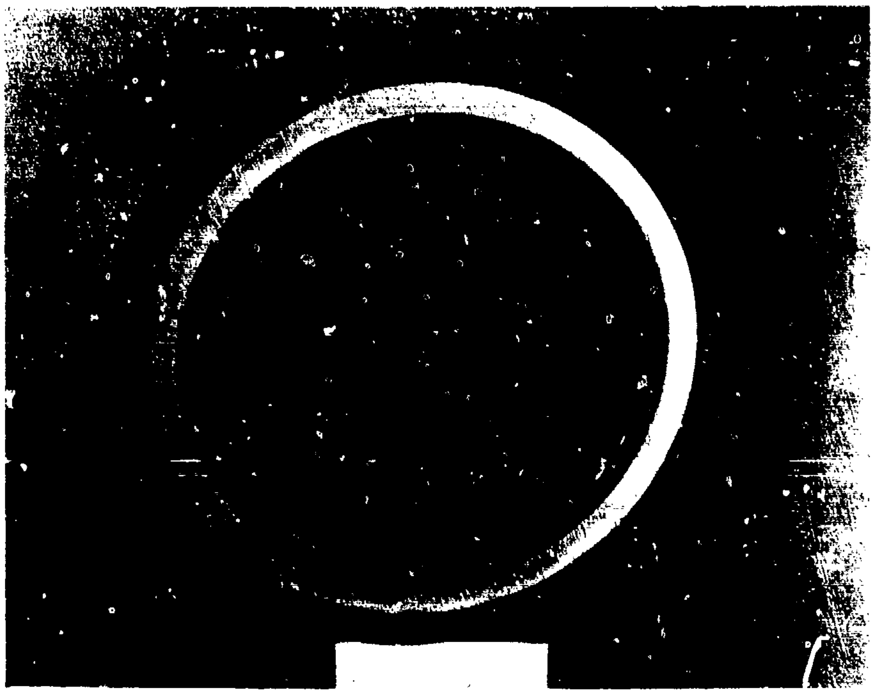


Figure 7. Number 5 Bearing

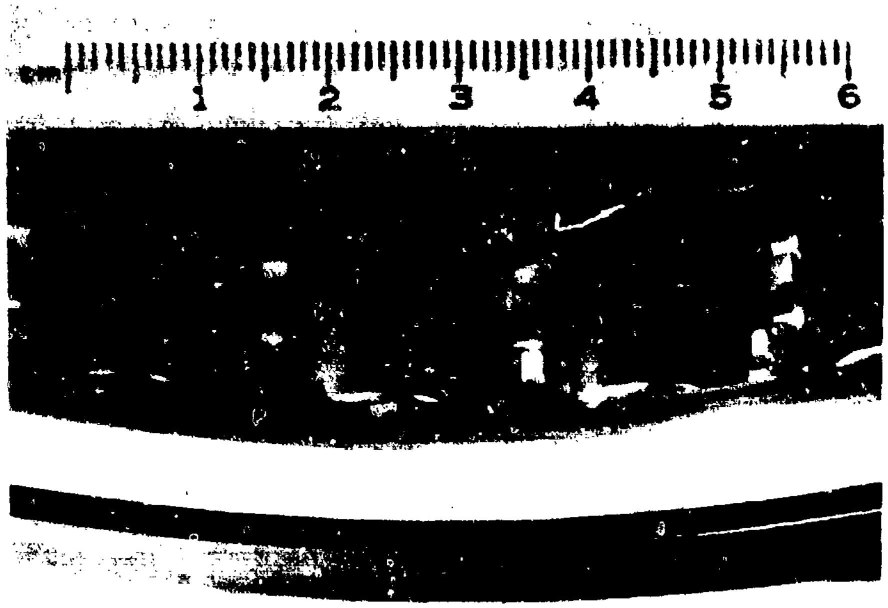


Figure 8. Wear of Number 5 Bearing Separator

Figure 9. Wear of Number 5 Bearing Inner Race

than 25 μm at one point to greater than 125 μm at the diametrically opposite point. The high trace silver content of the oil at 15 hours followed by sharp increases in trace copper and silicon content indicate that the abnormal wear began occurring very early in the simulator test. Note further, trace metal contents decreased or stabilized shortly after the sharp increases, further suggesting that the bearing wear occurred early in the test.

The trace from content and QDM^R counts increased in approximately the same proportion, as seen in Figure 10. These data do not indicate that QDM^R counts correlate with trace iron concentration in all wear situations, because the QDM^R detects large particles, and trace iron analysis generally measures very small particles and dissolved metal. The data do indicate that both QDM^R and SOAP analyses were able to detect abnormal wear in the test.

Ferrograms of several oil samples, diluted 9:1 of original concentration, were prepared. Scanning electron micrographs of several key ferrographic entry deposits are presented in Figure 11. The ferrogram show that a high level of wear debris was present in the lubrication system after only 10 test hours. Increasing amounts of bronze and steel rubbing wear particles were present up to 155 test hours. The 185 test hour ferrogram shows that less debris was present than at 155 test hours.

Direct reading (DR) ferrographic results [5] of the samples presented in Figure 11 are given in Figure 12. Again, samples were diluted 9:1 of original concentration. The same trends found in the analytical ferrograms were observed in the DR values. Small and large particle concentrations and wear severity index all increased up to 155 test hours, at which point the wear moderated. Evidently, clearances in the worn area of the number 5 bearing became large enough at 155 test hours for wear to decrease.

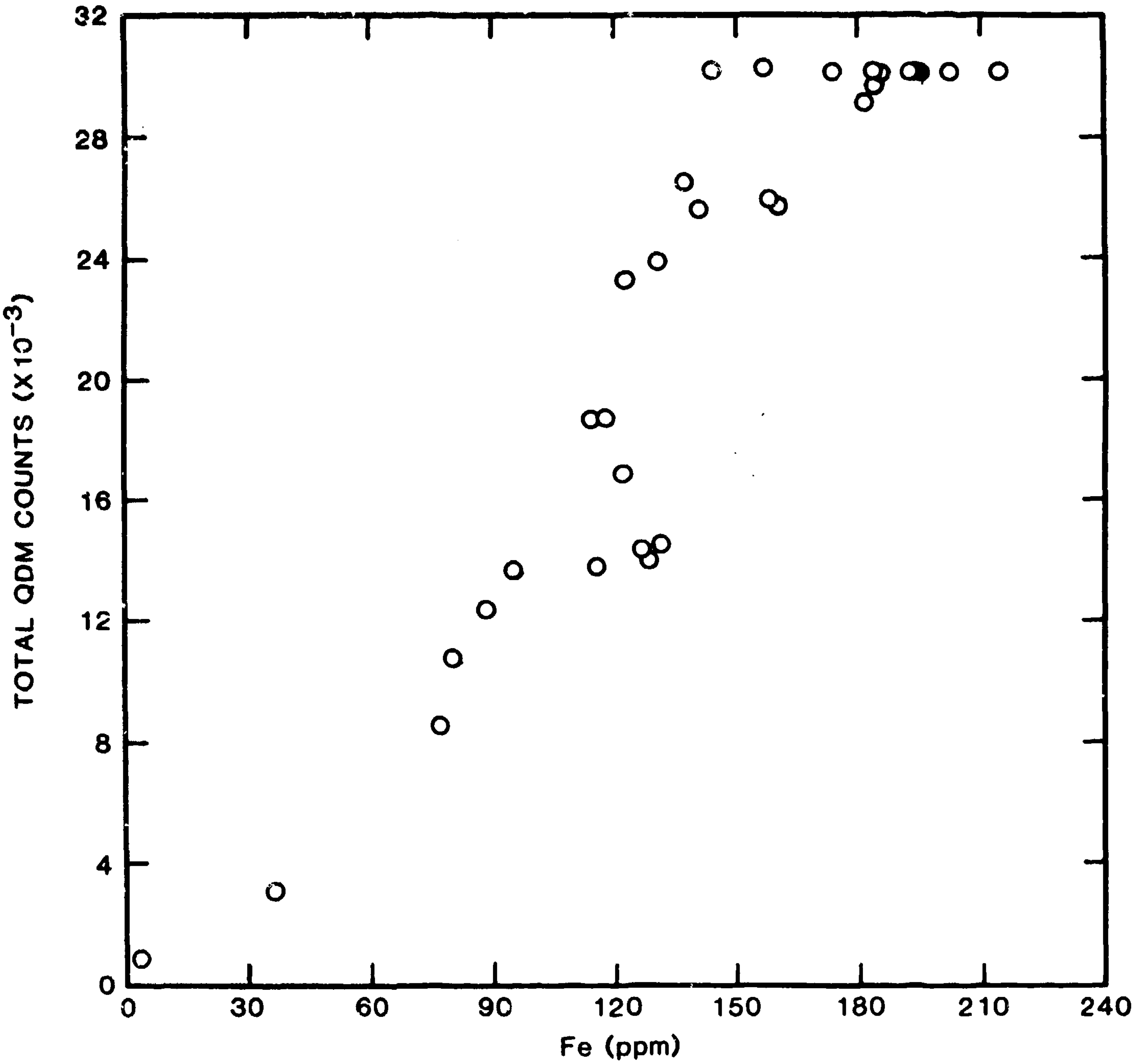
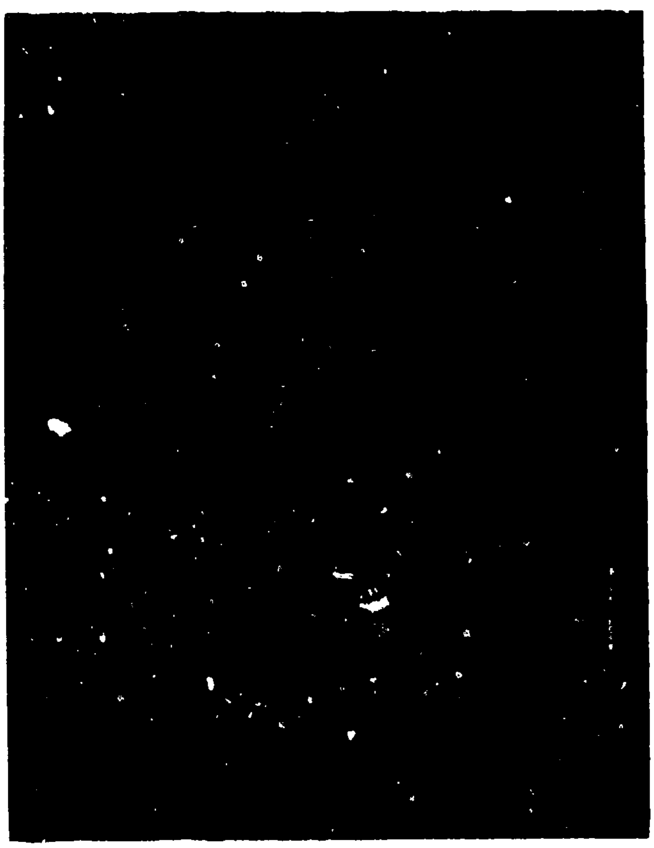


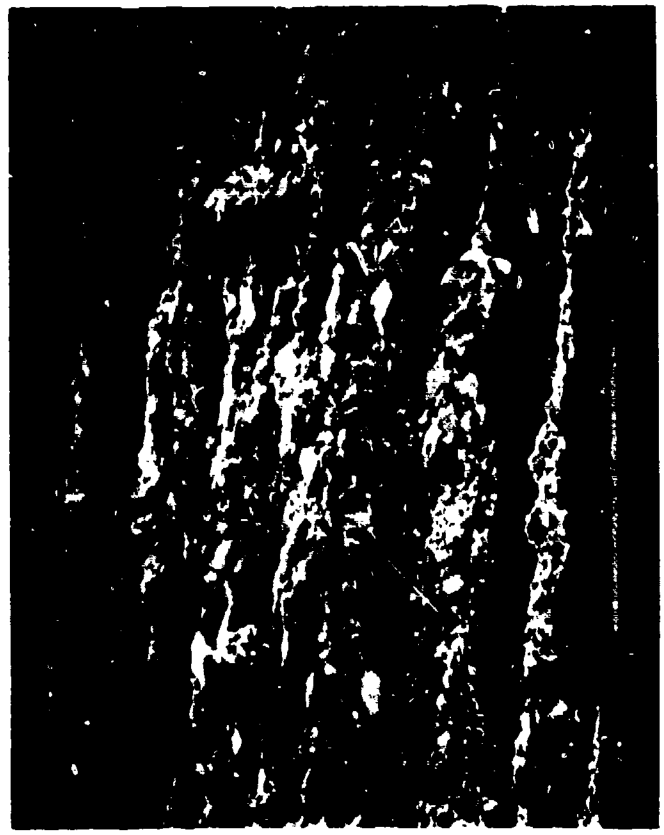
Figure 10. Total QDM[R] Counts Versus Iron Wear Metal Concentration



a) 0 Hours

b) 10 Hours

c) 155 Hours



d) 185 Hours

Figure 11. SEM Micrographs of Ferrographic Entry Deposits

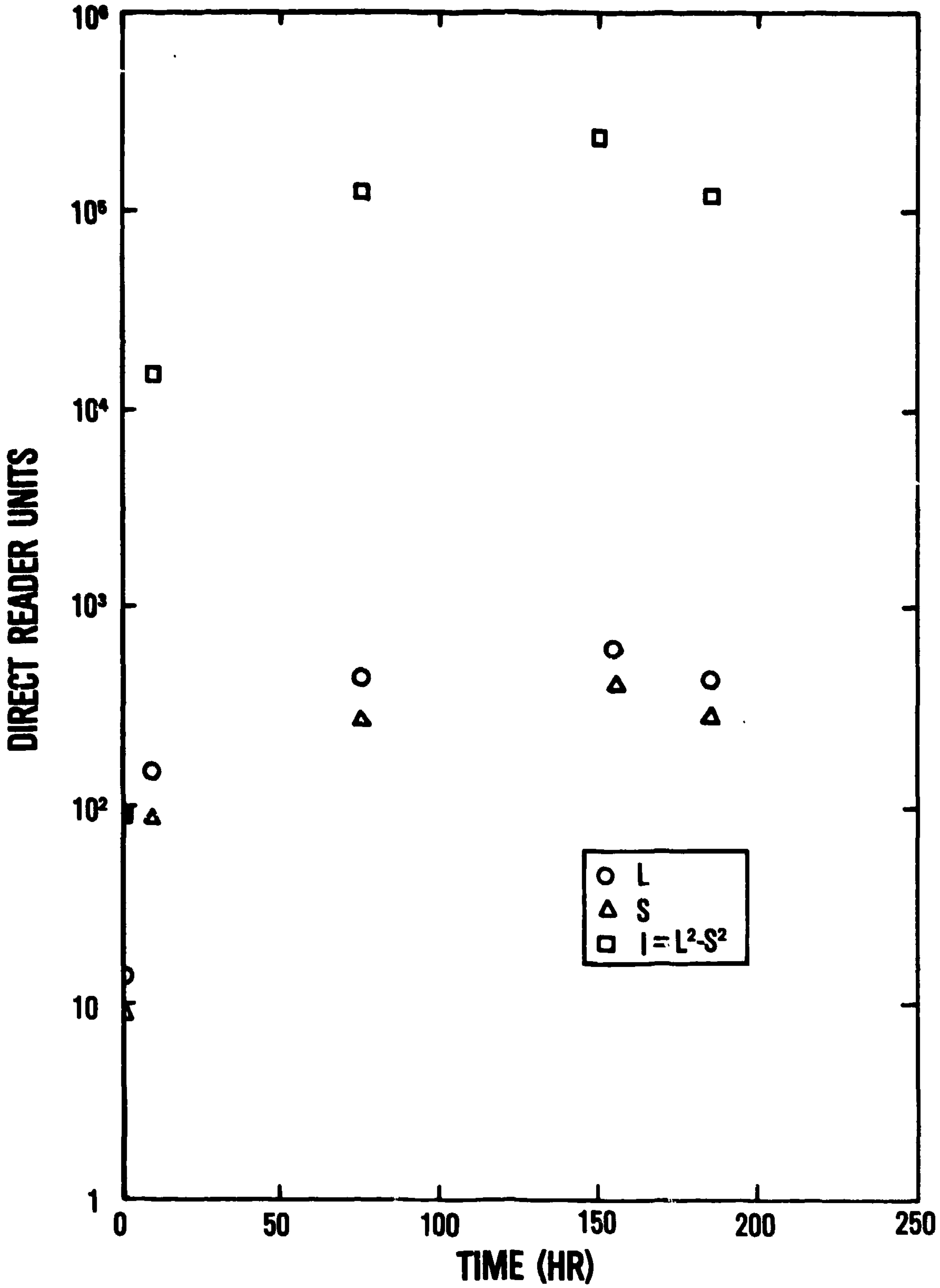


Figure 12. Direct Reading Ferrographic Results During Test

SECTION IV

CONCLUSIONS

a. The in-line COBRA unit successfully monitored the condition of the lubricant on a real-time basis. The in-line COBRA readings correlate well with laboratory COBRA readings and TAN.

b. The QDM^R detected the generation of wear within the simulator. Increases in trace iron content corresponded with QDM^R particle count increases. Ferrography and trace metal analysis of silver, silicon, and copper aided in identifying the number 5 bearing as the source of the abnormal wear. The wear of the bearing was confirmed on visual inspection.

c. Analytical and direct reading ferrographic data confirmed the rapid increase and subsequent modest decrease in wear debris concentration during the test.

d. The in-line COBRA and the QDM^R were used simultaneously for the first time to successfully monitor the condition of the lubricant and to assess wear condition in a flowing lubricant system.

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